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EARTH SCIENCE

Tarbuck ◆ Lutgens

Chapter 18

Moisture, Clouds, and Precipitation

18.1 Water in the Atmosphere

Water's Changes of State

- **Precipitation** is any form of water that falls from a cloud.
- When it comes to understanding atmospheric processes, water vapor is the most important gas in the atmosphere.

18.1 Water in the Atmosphere

Water's Changes of State

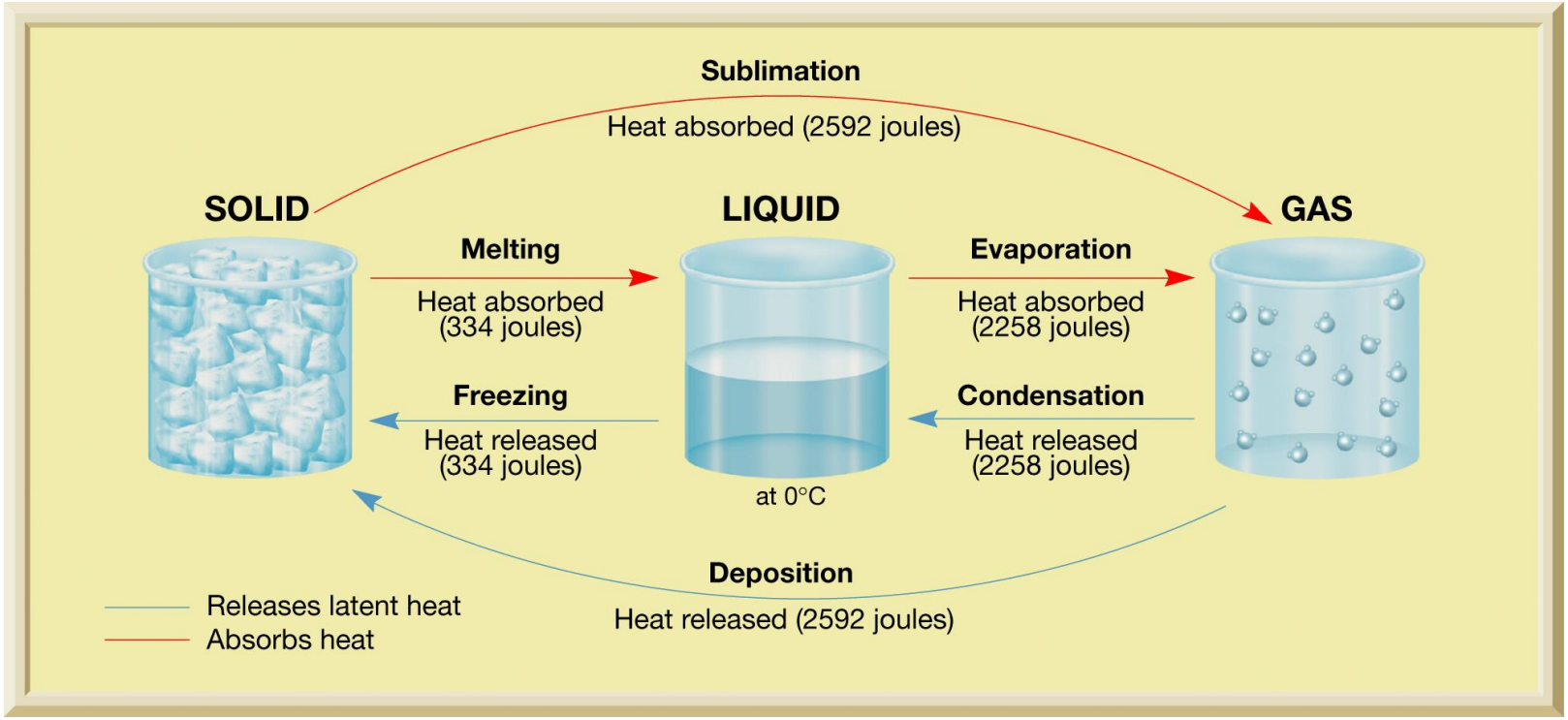
- Solid to Liquid
  - The process of changing state, such as melting ice, requires that energy be transferred in the form of heat.
  - **Latent heat** is the energy absorbed or released during a change in state.
- Liquid to Gas
  - **Evaporation** is the process of changing a liquid to a gas.
  - **Condensation** is the process where a gas, like water vapor, changes to a liquid, like water.

18.1 Water in the Atmosphere

Water's Changes of State

- Solid to Gas
  - **Sublimation** is the conversion of a solid directly to a gas without passing through the liquid state.
  - **Deposition** is the conversion of a vapor directly to a solid.

Changes of State



18.1 Water in the Atmosphere

Humidity

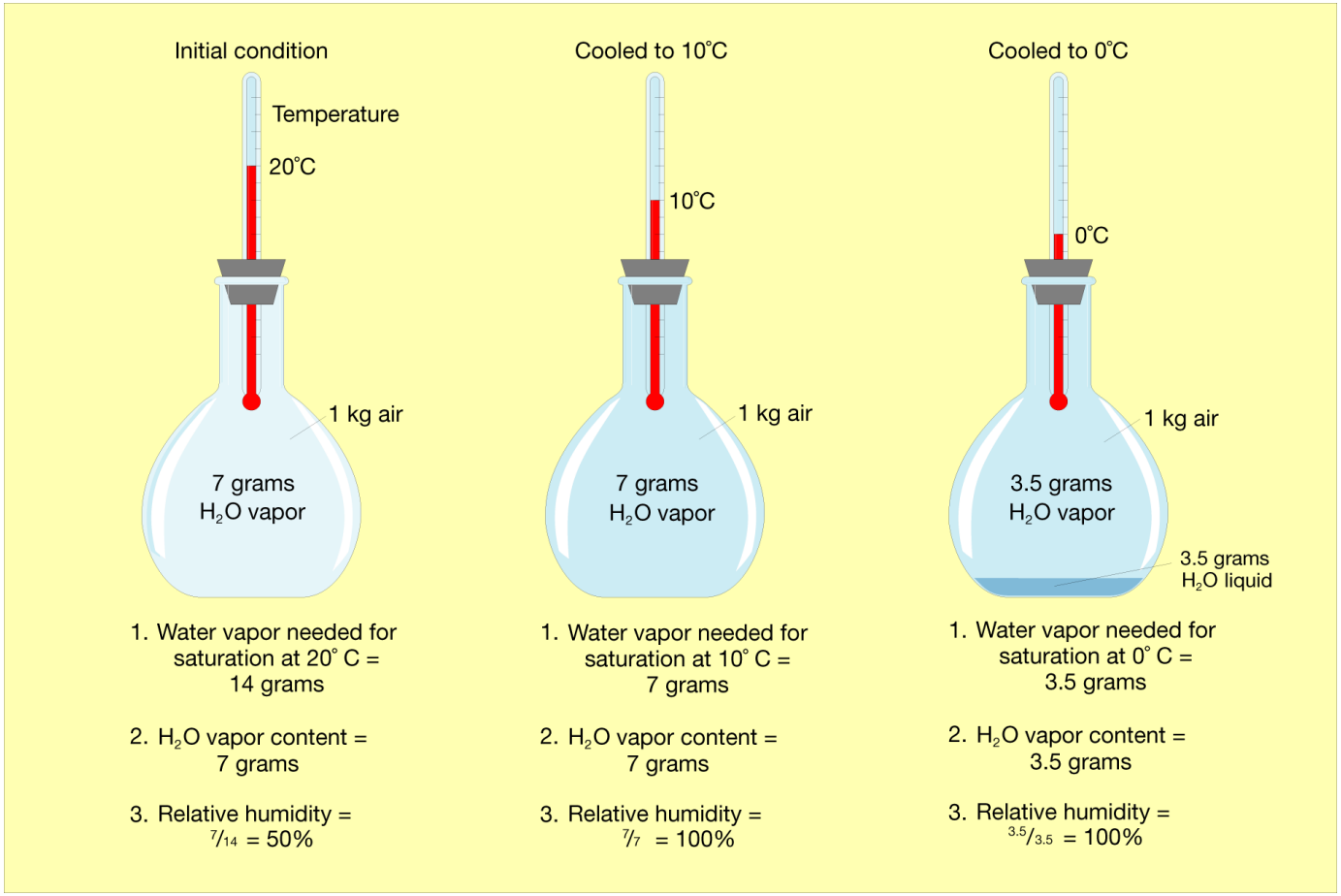
- **Humidity** is a general term for the amount of water vapor in air.
- Saturation
  - Air is **saturated** when it contains the maximum quantity of water vapor that it can hold at any given temperature and pressure.
  - When saturated, warm air contains more water vapor than cold saturated air.

18.1 Water in the Atmosphere

Humidity

- Relative Humidity
  - **Relative humidity** is a ratio of the air's actual water-vapor content compared with the amount of water vapor air can hold at that temperature and pressure.
  - To summarize, when the water-vapor content of air remains constant, lowering air temperature causes an increase in relative humidity, and raising air temperature causes a decrease in relative humidity.

Relative Humidity Varies with Temperature



18.1 Water in the Atmosphere

Humidity

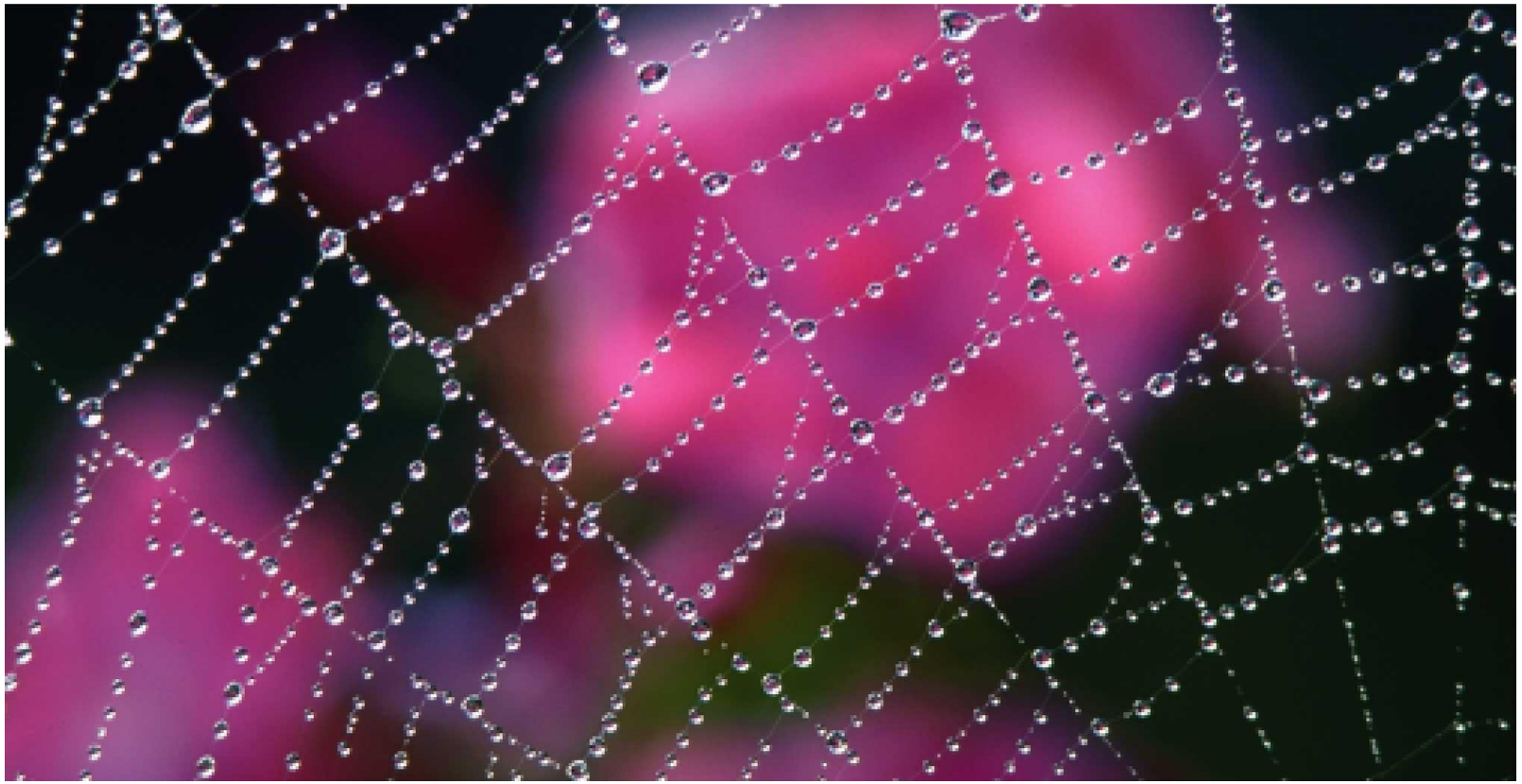
Dew Point

- **Dew point** is the temperature to which a parcel of air would need to be cooled to reach saturation.

Measuring Humidity

- A **hygrometer** is an instrument to measure relative humidity.
- A psychrometer is a hygrometer with dry- and wet-bulb thermometers. Evaporation of water from the wet bulb makes air temperature appear lower than the dry bulb's measurement. The two temperatures are compared to determine the relative humidity.

Dew on a Spider Web



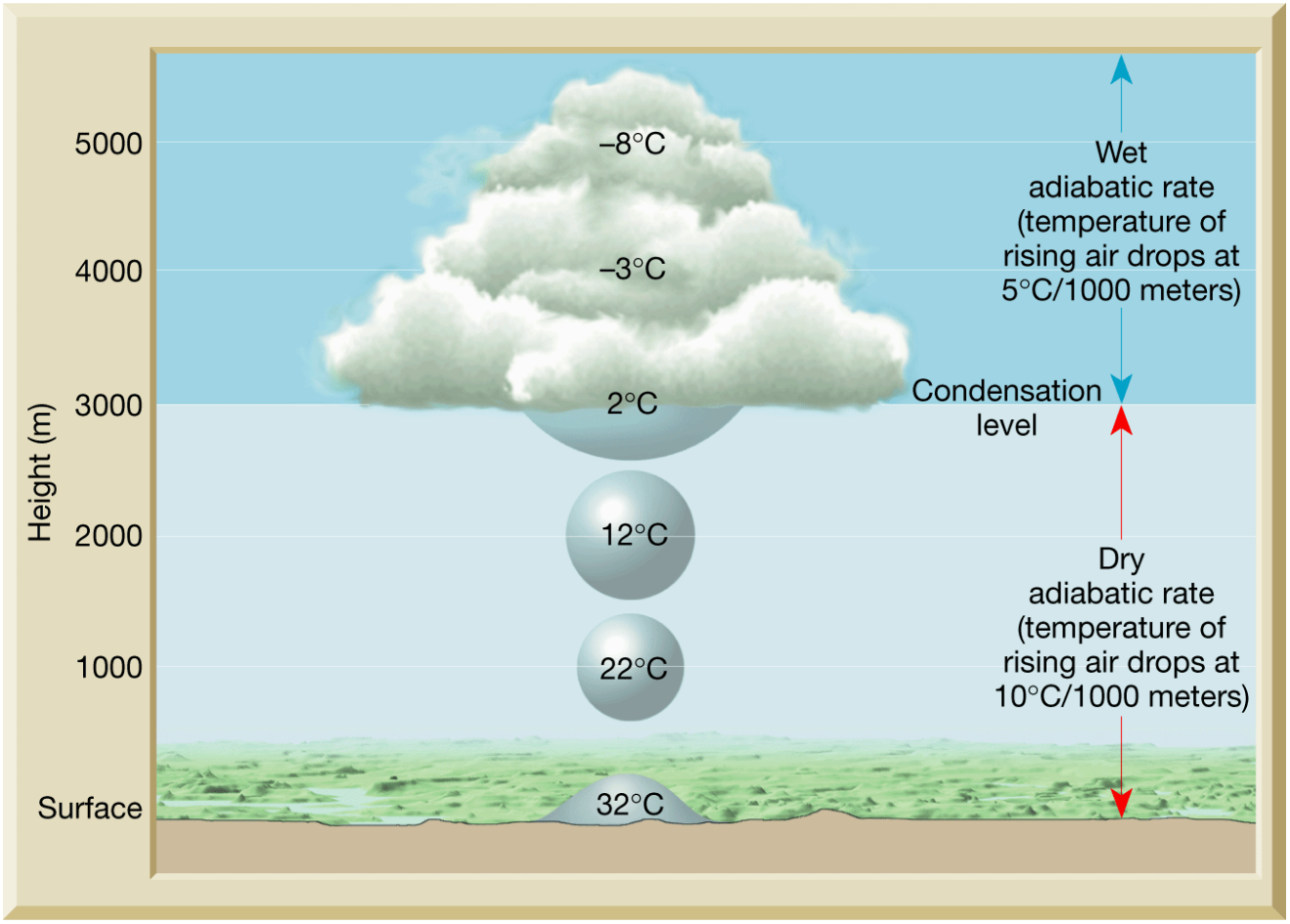
Sling Psychrometer

18.2 Cloud Formation

Air Compression and Expansion

- Adiabatic Temperature Changes
  - When air is allowed to expand, it cools, and when it is compressed, it warms.
- Expansion and Cooling
  - **Dry adiabatic rate** is the rate of cooling or heating that applies only to unsaturated air.
  - **Wet adiabatic rate** is the rate of adiabatic temperature change in saturated air.

Cloud Formation by Adiabatic Cooling



18.2 Cloud Formation

Processes That Lift Air

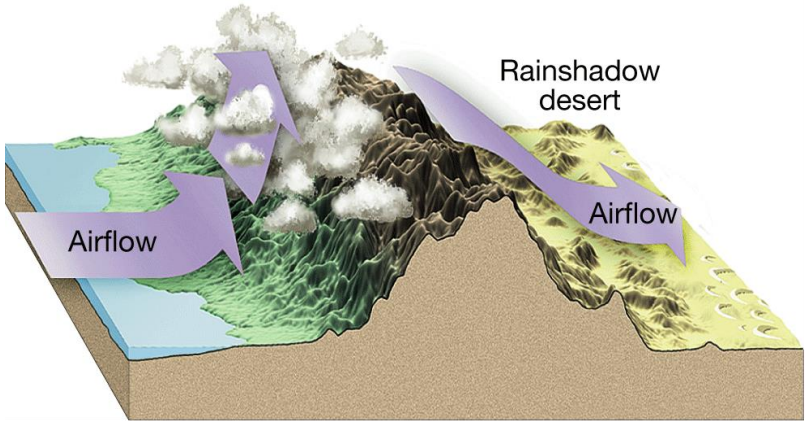
- Four mechanisms that can cause air to rise are orographic lifting, frontal wedging, convergence, and localized convective lifting.
- Orographic Lifting
  - **Orographic lifting** occurs when mountains act as barriers to the flow of air, forcing the air to ascend.
  - The air cools adiabatically; clouds and precipitation may result.

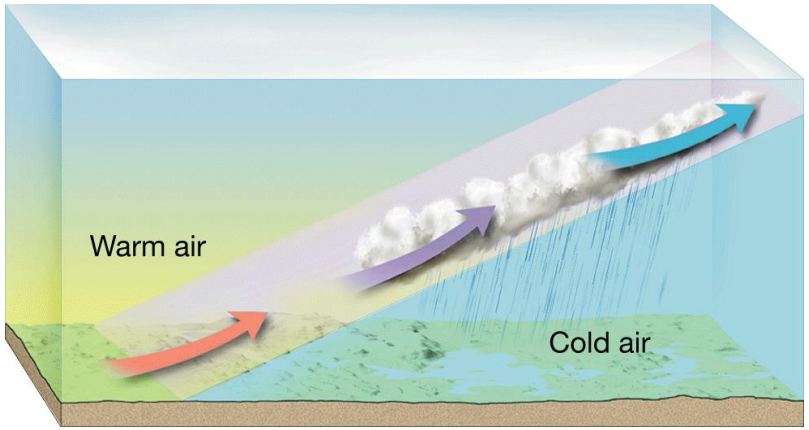
18.2 Cloud Formation

Processes That Lift Air

- Frontal Wedging
  - A **front** is the boundary between two adjoining air masses having contrasting characteristics.

Orographic Lifting and Frontal Wedging



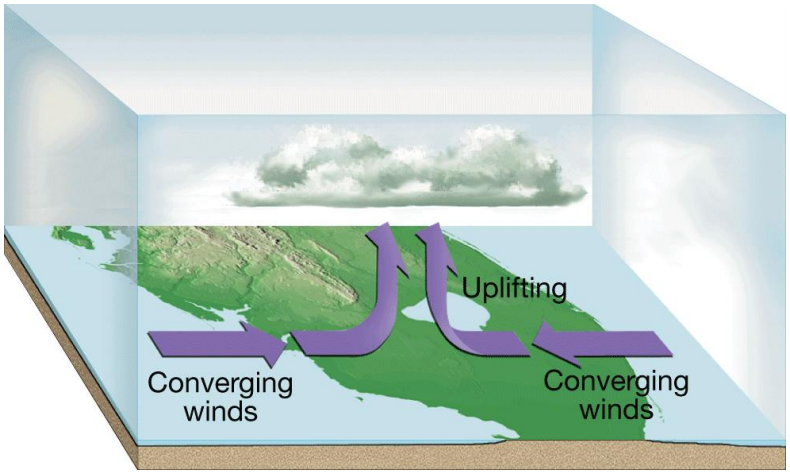


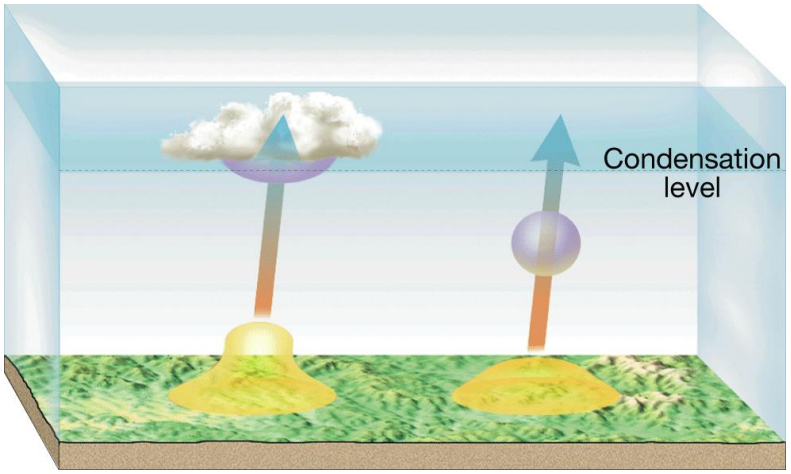
18.2 Cloud Formation

Processes That Lift Air

- Convergence
  - Convergence is when air flows together and rises.
- Localized Convective Lifting
  - Localized convective lifting occurs where unequal surface heating causes pockets of air to rise because of their buoyancy.

Convergence and Localized Convective Lifting





18.2 Cloud Formation

Stability

- Density Differences
  - Stable air tends to remain in its original position, while unstable air tends to rise.
- Stability Measurements
  - Air stability is determined by measuring the temperature of the atmosphere at various heights.
  - The rate of change of air temperature with height is called the environmental lapse rate.

18.2 Cloud Formation

Stability

- Degrees of Stability
  - A **temperature inversion** occurs in a layer of limited depth in the atmosphere where the temperature increases rather than decreases with height.
- Stability and Daily Weather
  - When stable air is forced above the Earth's surface, the clouds that form are widespread and have little vertical thickness compared to their horizontal dimension.

18.2 Cloud Formation

Condensation

- For any form of condensation to occur, the air must be saturated.
- Types of Surfaces
  - Generally, there must be a surface for water vapor to condense on.
  - **Condensation nuclei** are tiny bits of particulate matter that serve as surfaces on which water vapor condenses when condensation occurs in the air.

18.3 Cloud Types and Precipitation

Types of Clouds

- Clouds are classified on the basis of their form and height.
  - **Cirrus** (*cirrus* = curl of hair) are clouds that are high, white, and thin.
  - **Cumulus** (*cumulus* = a pile) are clouds that consist of rounded individual cloud masses.
  - **Stratus** (*stratus* = a layer) are clouds best described as sheets or layers that cover much or all of the sky.

Cirrus Clouds

18.3 Cloud Types and Precipitation

Types of Clouds

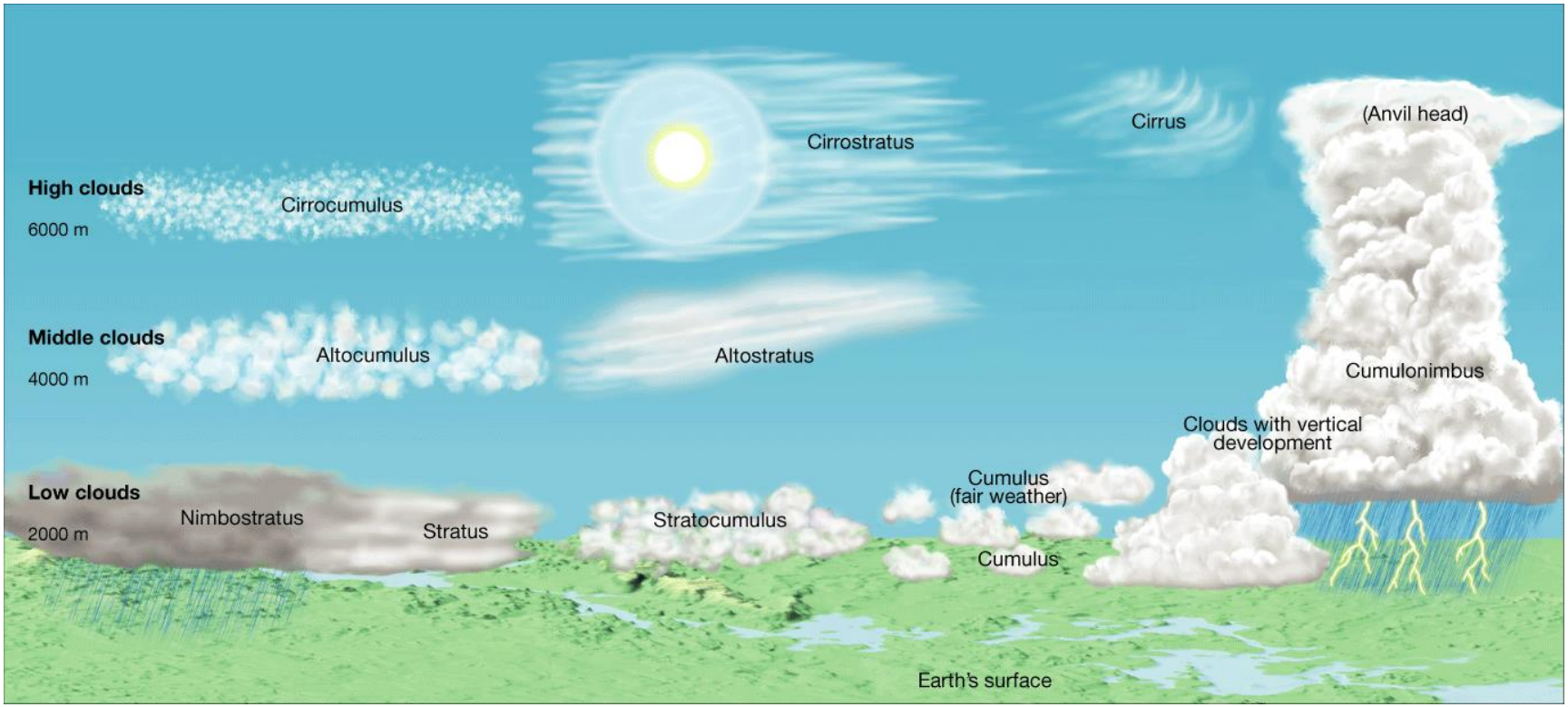
- High Clouds
  - Cirrus clouds are high, white, and thin.
  - Cirrostratus clouds are flat layers of clouds.
  - Cirrocumulus clouds consist of fluffy masses.
- Middle Clouds
  - Altocumulus clouds are composed of rounded masses that differ from cirrocumulus clouds in that altocumulus clouds are larger and denser.
  - Altostratus clouds create a uniform white to gray sheet covering the sky with the sun or moon visible as a bright spot.

18.3 Cloud Types and Precipitation

Types of Clouds

- Low Clouds
  - Stratus clouds are best described as sheets or layers that cover much or all of the sky.
  - Stratocumulus clouds have a scalloped bottom that appears as long parallel rolls or broken rounded patches.
  - Nimbostratus clouds are the main precipitation makers.

Cloud Classification



18.3 Cloud Types and Precipitation

Types of Clouds

- Clouds of Vertical Development
  - Some clouds do not fit into any one of the three height categories mentioned. Such clouds have their bases in the low height range but often extend upward into the middle or high altitudes.

18.3 Cloud Types and Precipitation

Fog

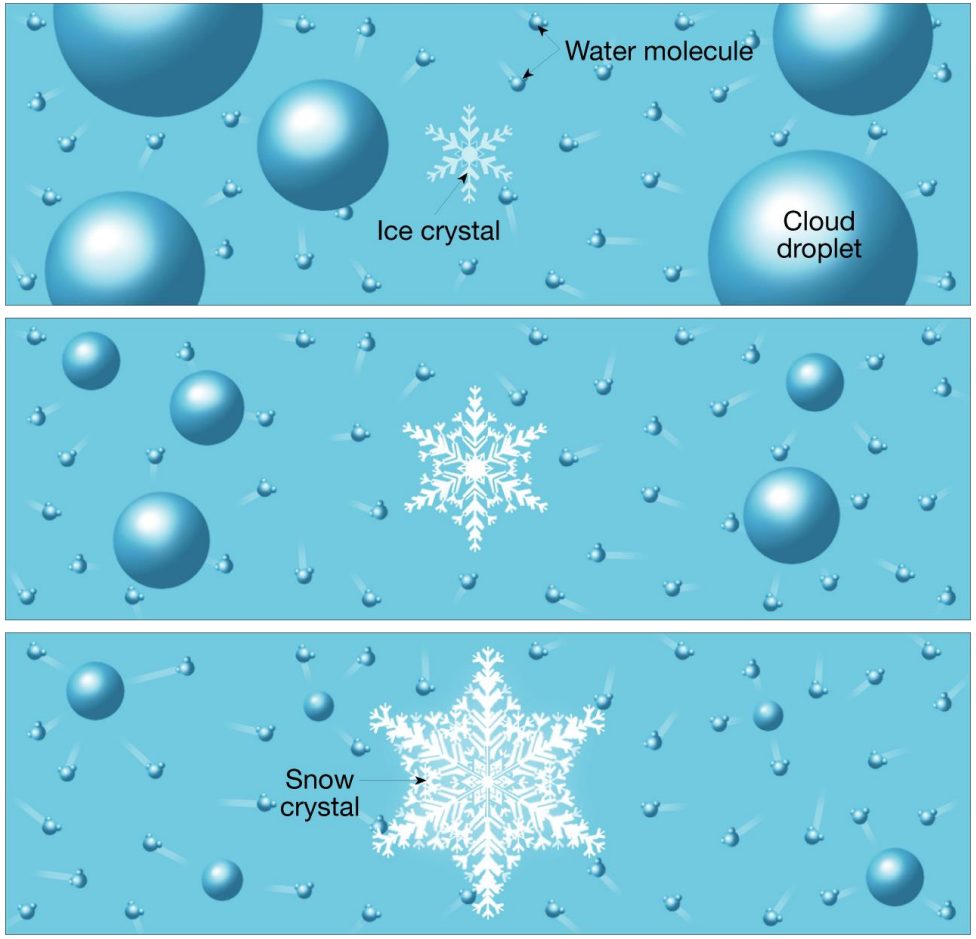
- Fog is defined as a cloud with its base at or very near the ground.
- Fog Caused by Cooling
  - As the air cools, it becomes denser and drains into low areas such as river valleys, where thick fog accumulations may occur.
- Fog Caused by Evaporation
  - When cool air moves over warm water, enough moisture may evaporate from the water surface to produce saturation.

18.3 Cloud Types and Precipitation

How Precipitation Forms

- For precipitation to form, cloud droplets must grow in volume by roughly one million times.
- Cold Cloud Precipitation
  - The **Bergeron process** is a theory that relates the formation of precipitation to supercooled clouds, freezing nuclei, and the different saturation levels of ice and liquid water.

The Bergeron Process



18.3 Cloud Types and Precipitation

How Precipitation Forms

- Cold Cloud Precipitation
  - **Supercooled water** is the condition of water droplets that remain in the liquid state at temperatures well below $0^{o}C$.
  - **Supersaturated air** is the condition of air that is more concentrated than is normally possible under given temperature and pressure conditions.

18.3 Cloud Types and Precipitation

How Precipitation Forms

- Warm Cloud Precipitation
  - The **collision-coalescence process** is a theory of raindrop formation in warm clouds (above $0^{o}C$) in which large cloud droplets collide and join together with smaller droplets to form a raindrop.

18.3 Cloud Types and Precipitation

Forms of Precipitation

- The type of precipitation that reaches Earth's surface depends on the temperature profile in the lower few kilometers of the atmosphere.
- Rain and Snow
  - In meteorology, the term *rain* means drops of water that fall from a cloud and have a diameter of at least 0.5 mm.
  - At very low temperatures (when the moisture content of air is low) light fluffy snow made up of individual six-sided ice crystals forms.

18.3 Cloud Types and Precipitation

Forms of Precipitation

- Rain and Snow
  - Sleet is the fall of clear-to-translucent ice.
  - Hail is produced in cumulonimbus clouds.
  - Hailstones begin as small ice pellets that grow by collecting supercooled water droplets as they fall through a cloud.

Largest Recorded Hailstone